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Before the  
FEDERAL COMMUNICATIONS COMMISSION  
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FEDERAL COMMUNICATIONS COMMISSION  
OFFICE OF SECRETARY

In the Matter of )  
 )  
Amendment of the )  
Commission's Rules )  
Concerning Maritime )  
Communications )

PR Docket No. 92-257

To: The Commission

DOCKET FILE COPY ORIGINAL

COMMENTS OF BR COMMUNICATIONS

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## SUMMARY

BR's linear FMCW "Chirpsounder<sup>®</sup>" technology is the *de facto* standard for much of the world's HF radio frequency management system. Essentially all of the linear FMCW sounder systems operating in the world today have been developed, manufactured, installed, and supported by BR. BR also has pioneered the extension of FMCW technologies to support commercial communications, and since December of 1994 has been operating under FCC developmental authority to determine the most effective and efficient means of integrating the benefits of its FMCW-based ALE technology into existing HF maritime communications systems.

Existing HF communications are subject to propagation uncertainties and operational difficulties that limit their usefulness for maritime and aviation communications. FMCW-based ALE can overcome these difficulties, thereby improving the quality, reliability, and ease of use of HF services and promoting the efficient use of the HF spectrum. As a result, FMCW-ALE can provide substantial public benefits by lowering aviation and maritime communications costs, providing reliable alternative communications paths for these users, and improving the operating safety and efficiency of ships and aircraft. For these reasons, the Commission should authorize the use of spectrally-efficient, state-of-the-art communications techniques such as FMCW-based ALE.

BR supports the Commission's proposal to permit the use of brief FMCW signalling for the purpose of ALE. However, the Commission should authorize FMCW-ALE in the band 2-30 MHz, rather than in the band 2-27.5 MHz as proposed in the FNPRM. Extending the band within which FMCW-ALE operations are authorized would provide benefits both to users operating in these higher frequencies as well as to those operating in bands below 27.5 MHz.

In addition to authorizing the use of FMCW-ALE, the Commission should permit the operation of channel sounding systems and should not mandate a single modulation standard. However, if the Commission decides that it must mandate a standard modulation, it should mandate FMCW signalling because this approach provides benefits that cannot be duplicated by channel sounding

systems. Whether or not the Commission adopts a single modulation standard, it should provide that new HF maritime systems should be designed and implemented to support FMCW-based ALE so as to enable the early implementation of a comprehensive FMCW-based ALE network.

With respect to the technical specifications required to protect those using HF frequencies for communications purposes from objectionable interference, the restrictions described in BR's prior comments in this proceeding and incorporated in the FNPRM are adequate to achieve this goal, and no further specifications or restrictions are required. In addition, there is no need to exclude frequencies used for data communications from FMCW-ALE sounding and, indeed, excluding these frequencies would adversely affect FMCW-ALE sounder operations.

Finally, while a number of functions should and likely will be supported by ALE systems, the Commission should not attempt to dictate either a minimum set of standards or an ALE protocol. The desired functions and the protocol implementations which best address those functions are application-specific, and as a result specifying even a minimum set of standards requires a ranking and bounding of the functions in an arbitrary way that is not — and cannot be — linked to the specifications desired for a particular application or service.

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**COMMENTS OF BR COMMUNICATIONS**

BR Communications ("BR") hereby comments on the Further Notice of Proposed Rulemaking in the above-captioned proceeding, released May 25, 1995 (the "FNPRM"). In particular, BR supports the Commission's proposal to permit the use of brief frequency modulated continuous wave ("FMCW") signalling under Parts 80 and 87 of the Commission's rules for the purpose of automatic link establishment ("ALE"). In addition, BR responds to the questions regarding FMCW signalling and ALE posed by the Commission in the FNPRM.<sup>1</sup>

BR has a strong interest in this aspect of the proceeding. Its linear FMCW "Chirpsounder<sup>®</sup>" technology is the *de facto* standard for much of the world's HF radio frequency management system. In 1967, BR introduced the first linear FMCW Chirpsounder to measure HF propagation conditions accurately and in real time, in order to support the operation and frequency management of military HF radio systems. Essentially all of the linear FMCW sounder systems operating in the world today have been developed, manufactured, installed, and supported by BR. Major military communications commands in the United States, Canada, the United Kingdom, France, Italy, Spain, Scandinavia, Australia, New Zealand, Japan, Taiwan, Saudi Arabia, and approximately fifteen other countries currently use BR's sounding technology for their HF radio communications.

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<sup>1</sup> FNPRM at ¶ 39.

BR also has pioneered the extension of FMCW technologies to support commercial communications. On December 14, 1994, it obtained FCC developmental authority to test the commercial use of its Chirpsounder technology.<sup>2</sup> Under this authority, it has conducted a series of tests to determine the most effective and efficient means of integrating the benefits of its FMCW-based ALE technology into existing HF maritime communications systems. Specifically, BR has operated two Chirpsounder transmitters continuously for more than a year, each sweeping four times per hour, 24 hours per day, and has conducted tests of the Chirpsounder's performance using both a mock ship's radio room and actual commercial ships operating in the Gulf of Mexico and the Atlantic Ocean.<sup>3</sup> These tests have enabled BR to develop extensive information about the system's operation, to improve the performance of its ALE hardware and control algorithm, and to confirm its belief, based on prior government and military operations, that Chirpsounder transmissions do not cause unacceptable interference to users of the HF band. By the end of the first year of developmental testing, BR's Chirpsounder system was able to pass a test message 94% of the time on the first call (*i.e.*, on the first frequency selected by the system) and 97% of the time by the third call when operating to a single service provider on a medium-length radio path<sup>4</sup> — a substantial improvement over the success rate of HF communications without a sounder. Work under the developmental authority has continued since this time, and the system's efficiency and performance has continued to improve.

**I. FMCW-BASED ALE IS IN THE PUBLIC INTEREST AND SHOULD BE AUTHORIZED.**

In previous filings in this proceeding and with regard to its developmental application, BR has discussed at length the difficulties associated with existing HF communications, the ways in which FMCW-based ALE can overcome these

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<sup>2</sup> BR's developmental authority has been amended on several occasions to permit higher-power transmissions, to add additional facilities to the test program, and to extend the initial one-year grant. See 7120-4, Dev/STA, 6.94; 7120-4, Dev/STA, 7.94; 7120-4, Dev/STA, 10.94; 7120-4, Dev/STA, 12.94; 7120-4, Dev/STA, 5.95.

<sup>3</sup> "BR Communications Report of Developmental Operations," submitted with BR Communications Request for Renewal of Developmental Authority, 7120-4, Dev/STA, 12.93 (filed Nov. 14, 1994). One of the transmitters has operated continuously since December 16, 1993; the other has operated continuously since August 12, 1994. *Id.* at 1.

<sup>4</sup> BR Request for Renewal of Developmental Authority at 2.

difficulties, and the resulting public interest benefits of using FMCW-ALE.<sup>5</sup> Briefly stated, FMCW-based ALE would:

- Improve the quality, reliability, and ease of use of HF services by: (i) increasing the availability (the fraction of time a user can pass acceptable traffic) and reliability of HF links; (ii) substantially increasing the HF bandwidth effectively available to users; (iii) improving the received signal-to-noise ("SNR") ratio such that messages do not have to be repeated; and (iv) enabling circuit re-establishment following ionospheric storms or other propagation disturbances.
- Promote the efficient use of the HF spectrum.
- Create a viable alternative to relatively high-cost maritime satellite communications, thereby enabling maritime operators to reduce communications costs.
- Improve the operating safety of ships by providing a usable backup when satellite communication is not possible, such as in severe weather, during failures of the ship's satellite communications equipment, or in regions of the earth not covered well by satellites.
- Improve trans-oceanic aviation communications, thereby improving flight efficiency and flight safety.

For these reasons, and as recognized in the FNPRM, authorizing the use of spectrally-efficient, state-of-the-art communications techniques such as FMCW-based ALE would be in the public interest. The Commission, therefore, should adopt rules permitting the use of brief FMCW signalling for the purpose of ALE.

Moreover, the Commission should authorize FMCW-ALE in the band 2-30 MHz, rather than in the band 2-27.5 MHz, as proposed in the FNPRM.<sup>6</sup> Frequencies between 27.5 and 30 MHz are allocated for international and domestic aviation communications,<sup>7</sup> and it therefore would be in the public interest to permit sounding in this band. Moreover, as discussed in Section V,

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<sup>5</sup> See Letter from Mr. Henry Goldberg on behalf of BR Communications, To Mr. William F. Caton, Acting Secretary, Federal Communications Commission, Washington, D.C. (filed Nov. 22, 1993); BR Communications Request for Special Temporary Developmental Authority, 7120-4, Dev/STA, at 10-13 (filed Oct. 12, 1993).

<sup>6</sup> FNPRM at ¶ 39; proposed rule § 80.229.

<sup>7</sup> See 47 C.F.R. § 87.173.

the strength of FMCW-ALE lies in the completeness of the information gathered. By lowering the upper frequency on which sounding is permitted, the Commission not only would limit the information available concerning the excluded frequencies, but also would degrade the system's ability to predict performance for frequencies below 27.5 MHz. Finally, there is no evidence that FMCW sounding in the 27.5-30 MHz band has caused objectionable interference to other users, and the FNPRM offers no explanation for the Commission's decision to impose an upper limit of 27.5 MHz rather than 30 MHz, as proposed by BR. For these reasons, sounding should be permitted over the band 2-30 MHz.

## **II. FMCW IS A SOUND APPROACH FOR IMPLEMENTING HF ALE.**

In the FNPRM, the Commission requests comment on whether FMCW signalling is the only way to implement HF ALE.<sup>8</sup> It is not, although as discussed in the following section it provides several benefits that cannot be matched by the alternative sounding technique.

There are two general classes of sounding or spectrum sampling techniques in service to support ALE protocols: channel sounding and the FMCW waveform. Channel sounding, as the name implies, involves sending probing signals on a user's own channels.<sup>9</sup> The FMCW waveform uses a linear FMCW sweep that moves at a constant rate across the HF band, operating with a very narrow instantaneous bandwidth and a very low peak power in order to minimize interference to other HF spectrum users.<sup>10</sup> Applying an algorithm, the information developed during the sweep is then used to determine channel quality and channel stability and to forecast frequency performance.

For the reasons discussed in the following section, both FMCW-ALE and channel sounding should be permitted under the Commission's rules. The Commission, however, should encourage a migration toward FMCW-based ALE systems.

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<sup>8</sup> FNPRM at ¶ 39.

<sup>9</sup> Channel sounding is a feature in MIL-STD 188-141A and FED-STD 1045.

<sup>10</sup> Transmissions on key time-standard and safety frequencies are excluded from the sweep.

**III. THE COMMISSION SHOULD NOT MANDATE A STANDARD ALE MODULATION BUT SHOULD TAKE APPROPRIATE STEPS TO PROMOTE THE INCORPORATION OF FMCW-ALE TECHNOLOGIES IN HF MARITIME SYSTEMS.**

There is no reason for the Commission to mandate a single standard modulation for ALE.<sup>11</sup> Both FMCW-ALE and channel sounding can be accommodated without causing interference to, or undermining the performance of, the other system. For this reason, the Commission should permit the use of existing ALE protocols as well as FMCW techniques, and should impose only those restrictions that are required to ensure that all ALE methods employed do not produce harmful interference to other users of the spectrum. This approach will provide the maximum flexibility to service providers and HF communications users and avoid “locking in” a single technology, while protecting users from objectionable interference.

However, if the Commission decides that it must mandate a standard modulation, it should mandate FMCW signalling because this approach provides benefits that cannot be duplicated by channel sounding systems.

In order to assess the relative merits of alternative sounding technologies, one must consider the essential ingredients and characteristics of an ALE procedure or protocol. The following capabilities are paramount:

- The system must support propagation assessment to include the timely measurement of SNR (including channel occupancy), multipath, dispersion or spread, maximum observed frequency (“MOF”), minimum observed frequency (“LOF”), and mode identification. The first three parameters define channel quality; the second three are necessary to choose stable frequencies and to forecast frequency performance reliably.
- The system must support order wire communications for network management.
- The above must be accomplished while minimizing interference to other users of the HF spectrum and to the communication services intended to be served.

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<sup>11</sup> See FNPRM at ¶ 39.

On the surface, channel sounding sounds elegantly simple: by testing only the channels over which a user may transmit messages, the operator can minimize interference to other users. In practice, however, channel sounding is inherently limited in its capability to measure and predict frequency performance.

It is now known that FMCW sounding can provide the network management information which will result in perfect network connectivity over long periods of time in temperate latitudes.<sup>12</sup> It is also known that FMCW sounding can provide the network management information which will result in network connectivity comparable to satellites in polar latitudes where geosynchronous satellites are in view, and can provide the only effective coverage at the highest latitudes.<sup>13</sup> In each case, FMCW sounding can provide these capabilities while maximizing network capacity.<sup>14</sup> In contrast, it is recognized that channel sounding cannot provide these benefits under a wide variety of conditions, although it can manage modest networks with a level of reliability that is acceptable to some users.<sup>15</sup>

The reasons channel sounding falls short are fundamental. In order to deal with the variability of propagation under disturbed conditions, channel sounding schemes must sample over the entire HF band and must sample a large number of communications frequencies. This process consumes communications resources, and thus decreases network performance when it is most needed. Moreover, in order to manage communications over an ocean area in a way that maximizes stability and capacity, it is necessary to forecast in time and interpolate spatially. In order to do this, MOFs, LOFs, and mode strength and identity (*viz* E<sub>s</sub>, F<sub>2</sub>, etc.) are required. Channel sounding cannot measure these parameters.

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<sup>12</sup> See Goodman, Ballard, and Sharp, "Practical Methods for Highly Reliable HF Communications," to be presented at *Milcom '95*, San Diego, Nov. 1995 (attached hereto as Attachment 1).

<sup>13</sup> *Id.*

<sup>14</sup> *Id.*

<sup>15</sup> Sutherland, "Simulated Effects of Sounding on Automatic Link Establishment HF Radio Network Performance," NTIA Report 93-291, NCS Technical Information Bulletin 92-21 (U.S. Department of Commerce: Dec. 1992).

The FMCW waveform efficiently measures all of the parameters required to maintain stability and maximize communications throughput, and can do so without consuming communications resources. With the information inherently available (MOF, LOF, and mode), a relatively few FMCW transmitters working with a large number of cooperating receivers can provide frequency management information over large ocean areas. FMCW-based ALE thus leaves communications assets available to communicate, rather than using them to sound.

In addition, an extremely robust “order wire” can be superimposed on the FMCW waveform, further augmenting the capabilities of the HF network and assuring that users are able to receive critical emergency and other messages even when fixed-frequency HF transmission techniques fail. Finally, twenty-nine years of use has shown that the FMCW waveform can achieve these benefits without causing interference to HF communications.<sup>16</sup>

For these reasons, the FNPRM appropriately identifies FMCW signalling as an appropriate approach to ALE. While BR believes that the Commission should not dictate a single ALE modulation standard, if it decides that adopting a single standard would serve the public interest, it should adopt FMCW-ALE. Moreover, in light of the benefits of the FMCW waveform discussed above, the Commission should provide that HF maritime systems should be designed and implemented to support FMCW-based ALE so as to enable the early implementation of a comprehensive FMCW-based ALE network.

**IV. THE SPECIFICATIONS DESCRIBED IN BR’S COMMENTS ARE ADEQUATE TO ENSURE THAT FMCW-BASED ALE WILL NOT CAUSE HARMFUL INTERFERENCE TO COMMUNICATIONS IN THE HF BAND.**

The FNPRM requests comment on the specifications that should be imposed to ensure that ALE will not cause harmful interference to communications in the HF band.<sup>17</sup> The restrictions described in BR’s prior

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<sup>16</sup> See, e.g., BR Request for Renewal of Developmental Authority at 3 (citing extensive government and military use of FMCW-based sounders and discussing BR’s developmental operations of its FMCW-based sounder, and stating that the above uses have caused no known objectionable interference, even at power levels of up to 100 watts).

<sup>17</sup> FNPRM at ¶ 39.

comments in this proceeding and incorporated in the FNPRM are adequate to achieve this goal, and no further specifications or restrictions are required.

Nearly thirty years of use of FMCW-ALE on a global basis provides ample evidence that FMCW-ALE systems operating in accordance with the technical restrictions outlined in BR's comments and specified in the FNPRM do not cause objectionable interference to those using the HF spectrum for communications purposes.<sup>18</sup> Simply stated, neither the nearly 150 Chirpsounder transmitters that have been deployed around the world during the past three decades for military and governmental communications uses, nor BR's nearly two years of developmental testing of the Chirpsounder system in commercial applications, have generated a single complaint of interference when operated in accordance with the parameters proposed in the FNPRM.<sup>19</sup>

The reason for this is embodied in the waveform design. Because the waveform is spread spectrum, it requires only a very limited amount of energy required to sound the HF frequencies. Because the system employs a "chirp" scanning approach, the residence time of the signal within a given elementary frequency band is momentary.

As a result, the specifications proposed in the FNPRM — limited transmitter power, a specified minimum sweep rate, a ceiling on the number of sweeps that may be conducted in any time period, and a provision to skip certain specified frequencies<sup>20</sup> — are sufficient to prevent objectionable interference HF communications from FMCW-ALE systems, and no additional restrictions should be imposed.<sup>21</sup>

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<sup>18</sup> See n.16, *supra*.

<sup>19</sup> As noted in BR's previous comments in this proceeding, BR is aware of a single complaint of interference caused by a transmitter with an EIRP of approximately 600 watts sweeping twelve times an hour. BR Comments, *supra* n.5, at 3 n.6. See also BR Request for Developmental Authority at 7 n.3.

<sup>20</sup> FNPRM, proposed § 80.229.

<sup>21</sup> This discussion addresses only the conditions needed to prevent interference by FMCW-ALE systems. If Channel Sounding also is permitted, appropriate restrictions should govern those operations. These restrictions should incorporate the Channel Sounding standards contained in MIL-STD 188-141A and FED-STD 1045.

**V. THE COMMISSION SHOULD NOT REQUIRE FMCW-ALE SYSTEMS TO AVOID DATA COMMUNICATIONS CHANNELS.**

The FNPRM expresses concern that FMCW signalling may be detrimental to HF data communications and, therefore, requests comment on whether channels designated for facsimile, radio-printing, or data communications should be protected in the same way as distress frequencies (*i.e.*, by requiring FMCW transmitters to “skip” these frequencies when conducting a scan).<sup>22</sup>

The Commission should not impose additional restrictions on FMCW operations in order to protect data communications, because such restrictions would be both unnecessary and detrimental to ALE operations.

FMCW signalling will not cause objectionable interference to any reasonably modern HF data service employing simple error correction. BR is not aware of a single case of objectionable interference to a facsimile or radio-printing service from FMCW-ALE systems operating in accordance with the specifications proposed in the FNPRM, despite the fact that BR currently is operating FMCW transmitters and receivers that are co-located with radio-printing and data services and has operated FMCW transmitters that were co-located with facsimile receivers.

Further restricting FMCW operations in order to protect HF data communications services not only is unnecessary, it would be detrimental to the successful operation of FMCW-ALE systems. The FMCW technique’s strength lies in the completeness of the information gathered. By requiring that FMCW sounders avoid frequencies, the Commission not only prevents these systems from gathering information about the performance of the frequencies that are avoided, but also undermines the completeness of the overall information about performance within the HF band. As a result, these restrictions undermine the system’s ability to forecast performance reliably. While FMCW-ALE can accommodate the “blanked-out” frequencies proposed in the FNPRM, increasing the number of “blanked-out” frequencies could adversely — and unnecessarily — affect system performance.

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<sup>22</sup> FNPRM at ¶ 39.

**VI. THE COMMISSION SHOULD NOT MANDATE MINIMUM ALE REQUIREMENTS OR SPECIFY AN ALE PROTOCOL.**

The FNPRM lists several capabilities that could be supported by an ALE system, including automatic signalling and response, selective calling, analysis of channel quality, link maintenance, data transfer, and error checking, and requests comment on whether the Commission should mandate minimum ALE standards.<sup>23</sup> An additional basic capability not listed in the FNPRM is full-band FMCW sounding to enhance the overall ALE functionality and provide the most reliable real-time, effective assessment of propagation conditions, as discussed in Section III.

As demonstrated by BR's initial comments and the FNPRM, the primary thrust of the Commission's ALE proposal is to enable users to measure and use HF spectrum more efficiently and reliably by employing a superior approach for analyzing propagation conditions. The measurement of propagation conditions is the central function of an ALE standard. It is not, however, the only function, as the FNPRM recognizes.<sup>24</sup>

While these additional functions should and likely will be supported by ALE systems, the Commission should not attempt to dictate either a minimum set of standards or an ALE protocol. The desired functions and the protocol implementations which best address those functions are application-specific, and are quite dependent on the tolerance of a service to decreased SNR, increased multipath, dispersion and interference, and tolerance of delay. For example, a modern data service would have significantly different implementations from a modern telephony service, and various types of data services will have to deal with each of the above considerations in an optimum way. Specifying even a minimum set of standards requires a ranking and bounding of the functions in an arbitrary way that is not — and cannot be — linked to the specifications desired for a particular application or service. As a result, the FCC should not specify in any detail the specifications which an ALE system must support or the

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<sup>23</sup> Id.

<sup>24</sup> Some of the functions listed in the NPRM and often subsumed within the term "ALE" actually deal with the maintenance, rather than the establishment, of a link. In urging the Commission not to establish minimum ALE standards or an ALE protocol, BR refers to both true "ALE" functions as well as automatic link retention functions.

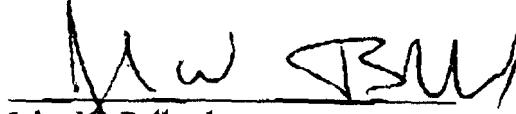
form which an ALE protocol should take. Rather, it should leave this process to the market and, where necessary and appropriate, to industry standards bodies.

CONCLUSION

For the reasons stated herein and in BR's initial comments in this proceeding, the Commission should promptly adopt rules which permit the use of FMCW-ALE and other sounding technologies in the 2-30 MHz HF band.

Respectfully submitted,

BR COMMUNICATIONS

A handwritten signature in black ink, appearing to read "JW Ballard", written over a horizontal line.

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# PRACTICAL METHODS FOR HIGHLY RELIABLE HF COMMUNICATIONS

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## Abstract

Since 1993, TCI/BR investigators have been examining the potential of frequency and path diversity in solving many of the problems which have longed plagued HF communication systems and have hindered its effectiveness. While our results have application to voice communication, our primary motivation is directed toward the improvement in reliability for conveyance of digital data. Paths include polar cap, auroral zone, high-latitude trough, as well as mid-latitude channel environments. These paths have been selected to ascertain the relative correlation properties under both benign and pathological conditions, and the resultant data are being used to validate emerging real-time ionospheric and HF performance prediction models. These results have application for design and operation of highly reliable HF DL service for DoD applications in stressed environments and in various aeronautical-mobile and maritime applications. In this paper, we will outline the importance of path and frequency diversity toward the improvement in system availability. Emphasis will be given to results which have been obtained from an analysis of radio paths within the high latitude and arctic regions. These have been selected since the pathological behavior exhibited by the relevant skywave channels provides us with an abundant opportunity to test our several design hypotheses based upon application of diversity. We have developed estimates of performance for an HF data link service based upon Chirpsounder<sup>TM</sup> records and HF DL modem specifications [1].

## 1 Introduction

There is a common perception that long-haul HF communications are intrinsically unreliable owing to the fact that the skywave channel is a dispersive, birefringent, and dissipative medium. This perception has largely been based upon the experience obtained over the years prior to the advent of digital data communications and the development of modern DSP technologies and adaptive HF schemes. While the reality is distinctly different from perception in the modern era, designers of communication systems must still be mindful of the variabilities of the HF channel. The HF channel has a rich personality which is far from featureless. Even the benign channel exhibits a diurnal texture, and frequency management strategies must account for variations in the instantaneous propagating bandwidth.

The HF channel behavior is even more exaggerated in those phenomenological regimes which are characterized by temporal and spatial variability. The nature of ionospheric variability is described by Goodman [2]. The most obvious of these regimes are exemplified by natural disturbances associated directly or indirectly with solar flares, geomagnetic storms, atmospheric tidal forces, atmospheric gravity waves, and related disturbances. These effects are decidedly region-specific. One well known class of disturbances which are directly coupled to solar flares is termed a Sudden Ionospheric Disturbance (SID), and the disturbances which derive from this class will impact HF paths which are immersed in daylight. The effects are virtually immediate since the flare radiation travels with the speed of light. The Short Wave Fade (SWF) is a prime example in this class of disturbances. Other forms of disturbance are delayed, since they derive not from electromagnetic flux, but rather from the interaction of the earth's magnetoionic medium with charged particles emanating from the sun. These particles traverse the interplanetary medium in hours to days, either collectively, as a neutral plasma (i.e., solar wind), or individually, as highly energetic ionic species. The solar wind compresses the magnetospheric plasma giving rise to an hierarchy of ionospheric disturbances exemplified by the so-called ionospheric storm at mid-latitudes and auroral disturbances at high latitudes. Polar Cap Absorption (PCA) is a particularly insidious phenomenon which derives from energetic protons which create excess D-region ionization with the polar cap, a vast region interior to the locus of auroral arcs known as the auroral oval. PCA events introduce 100s of dBs of signal attenuation for HF circuits which pass through the polar cap. The aurora itself may introduce absorption or scatter paths which are not wholly predictable. There are also other disturbances which are associated with the motion of atmospheric gravity waves, and these are referred to as Traveling Ionospheric Disturbances (TIDs). These features represent the principle source of unpredictable variability for HF circuits at mid-latitudes. Over the equator, ionospheric stratification and spread-F are dominant features of the nocturnal environment. In all geographical regimes, HF circuits are subject to variations in the maximum and minimum usable frequencies.

## 2 Using Diversity to Advantage: A Practical Approach

The range of ionospheric and HF channel variability may be measured with instruments such as sounders, and the median representation of key ionospheric and HF propagation parameters may be estimated through use of models based upon sounder data. Indeed, codes such as IONCAP, VOACAP, and ICEPAC are used by communication specialists to predict circuit or network performance over specified paths, geophysical conditions, and for specified months and times of day. Unfortunately, models do not enable one to predict how the channel will behave especially during disturbed periods.

Figure 1 illustrates the impact of a magnetic storm on the channel properties for May 5-6, 1993 for two paths linking Sunnyvale (California) to sites in Hawaii and Utah. The raw data was obtained from Chirpsounder oblique-incidence-

ionograms which exhibited the Lowest Observable Frequency (LOF) and the Maximum Observable Frequency (MOF). Diurnal variation of the Lowest Usable Frequency (LUF) and the Maximum Usable Frequency (MUF) are deduced from IONCAP, and they show the usual diurnal variation one would anticipate for the two mid-latitude paths. But the actual records reveal an entirely different behavior, one which cannot be forecast with any accuracy, unless the model being used is updated with real-time data. The Chirpsounder data reveals a storm-time diminution in the MOF along with an enhancement in the presunrise MOF. Clearly reliance on predictions will not suffice for the type of disturbance exhibited here, since the frequency range which is predicted with IONCAP is virtually "out-of-phase" with the band of frequencies which are observed (by Chirpsounders) to propagate over the two paths.

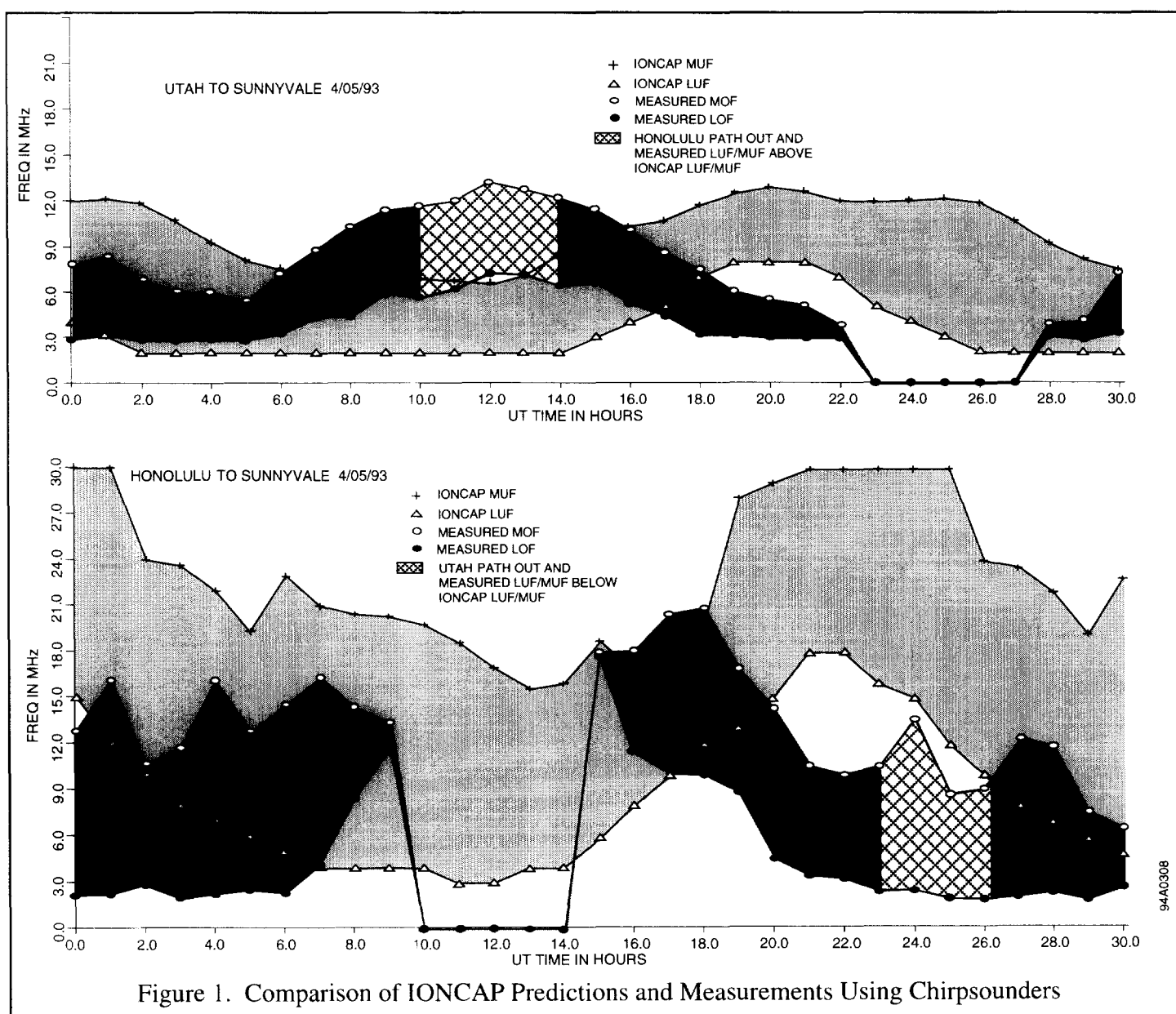
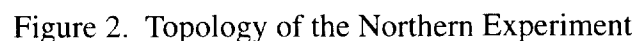


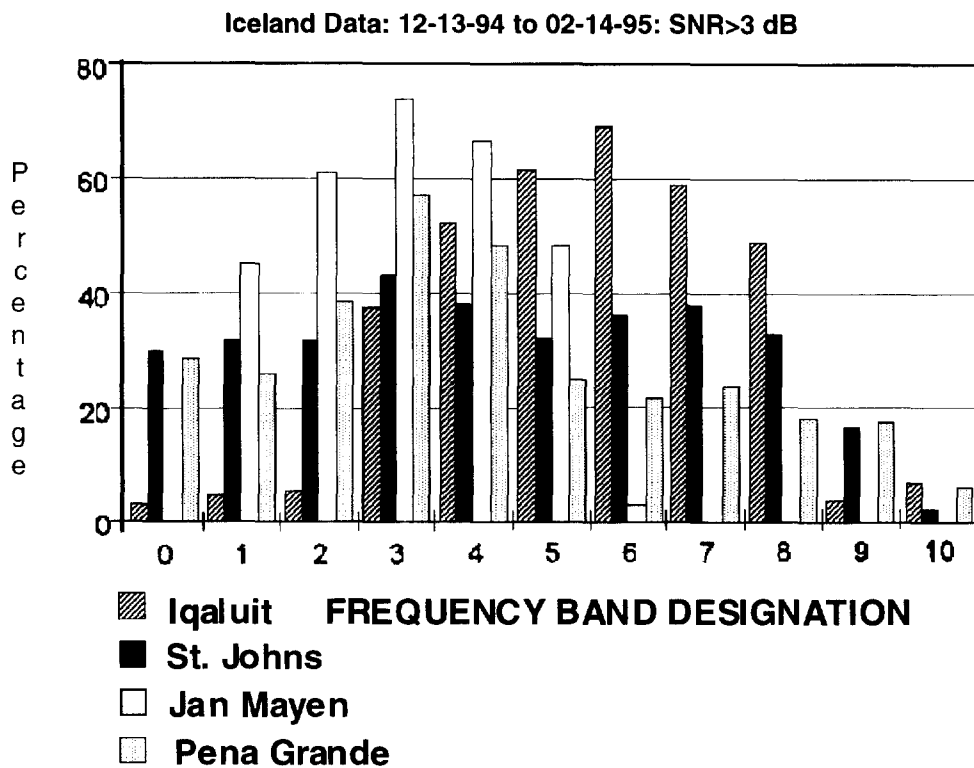
Figure 1. Comparison of IONCAP Predictions and Measurements Using Chirpsounders

The data shown in Figure 1 was derived from the first of two complementary data collection campaigns. The first campaign, in 1993-94, involved the collection of HF channel properties over a set of four (4) midlatitude paths, with a receiver at Sunnyvale being a common node for transmitters located in Hawaii, Utah, North Carolina, and Puerto Rico. Data was collected continuously for 1/2 year, and the results have shown the very significant power of path diversity in the maintenance of connectivity between the base station and at least one of the distant nodes at any given time. With access to a fixed number of frequencies, we have demonstrated that acceptable high frequency data link (HF DL) reliabilities, with data rates in the range of 300 to 1800 bps, of the star-net configuration may be achieved virtually 100% of the time. The fact that we have observed full availability of HF DL service from Sunnyvale to one or more of the distant nodes is all the more remarkable given the fact that magnetic storms were sometimes in evidence during the trials. Such events typically limit the bandwidth for a single propagation path at specified universal times.

For mid-latitude paths which branch into separated azimuthal sectors, or which exhibit significant "control point" separations, one finds that the unpredictable variability is poorly correlated. While this situation is unfortunate if we wish to extrapolate ionospheric information from one location to another, it is possible to improve network connectivity through use of path diversity. An application of special relevance is the maintenance of connectivity for aircraft flying in oceanic areas, and especially in those zones for which SATCOM reliabilities are degraded by virtue of limited visibility (viz., transpolar routes) or because of various media



3a



3b

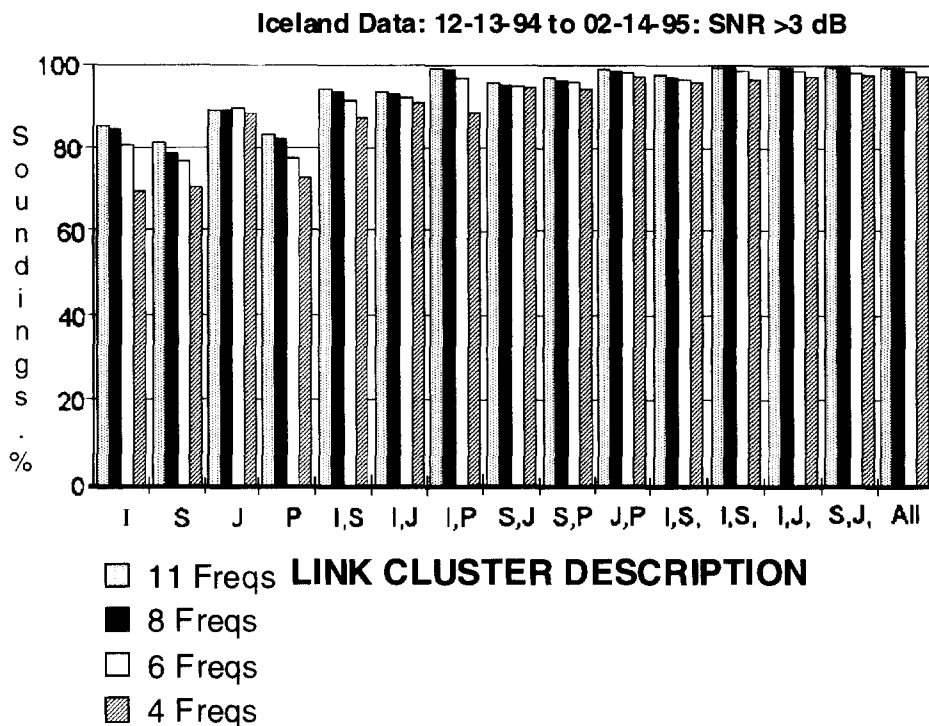


Figure 3. Data for the time period of 12-13-94 to 02-14-95.

Receiver at Iceland and transmitters at Iqaluit (I), St. Johns (S), Jan Mayen (J), and Pena Grande (P).

(Fig. 3a: top) Percentage availability vs. frequency band designation for each transmitter.

(Fig. 3b: bottom) Percentage availability vs. link cluster designation for the following groups of frequencies: 11, 8, 6, and 4. The link cluster designation refers to the grouping of stations which are allowed to participate.

impairments, including rainfall attenuation and ionospheric scintillation. We maintain that path diversity and dynamic frequency management (i.e., full sharing of frequencies as required) among designated HF service providers will have the potential for development of a practical HF DL system, even for high latitudes. But there are still questions to answer. For example, how many frequencies are really needed for the regional service? How many service providers are needed, and where should they be located to achieve the degree of space diversity required? Accordingly, TCI/BR initiated an experimental program which we have dubbed the "Northern Experiment". The purpose of this experiment is to gather propagation data over numerous high latitude and polar paths enabling an analysis to be made of the projected performance of an HF DL system. The experimental design is given below.

### 3 Nature of the Experiment

A major consideration in station selection for the Northern Experiment was a need to mimic as closely as possible the climatological conditions to be experienced by HF DL over a generic set of aircraft flight paths across the North Atlantic. To do this we recognized that ionospheric conditions in the F region are best organized by geomagnetic field considerations rather than geographic coordinates. Accordingly, we map the source to a candidate proxy environment along magnetic field lines. We refer to this process, if done successfully, as climatological invariance.

A number of Chirpsounder nodes were established for the Northern Experiment. Figure 1 is a map of the deployment. Each receiver site was programmed to recover ionograms from up to four transmitters at a rate of twice per hour. The Chirpsounder receiver passed the digital ionograms to a storage device which was controlled by a collocated PC. The sites were equipped with an upload feature which could be initiated through a dial-up capability. All data sets were uploaded to a central processing facility located at Sunnyvale California.

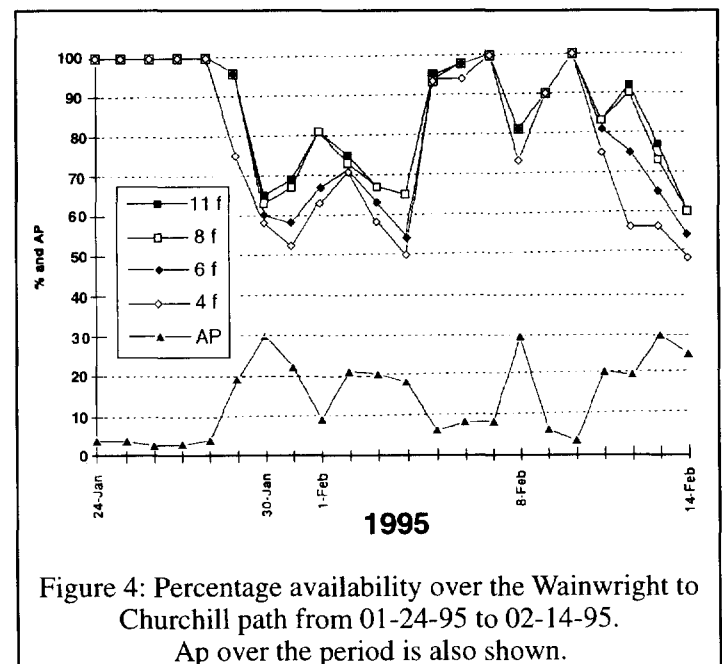
Analysis of data has been conducted with the view directed toward the elucidation of HF DL performance for specified service areas (determined by a given group of Chirpsounder nodes) for various groups of frequencies. The Chirpsounder system provides data for the entire HF band excluding a limited number of blocked channels. We extracted data from the Chirpsounder records at specified Aeronautical-Mobile (AM) bands which were also covered by the Chirpsounder scan. We also obtained estimates of the noise level for each AM band, and we computed the Signal-to-Noise ratio (SNR) for each band. These data were compared with the minimum values of SNR required to pass traffic at bit rates from 300 to 1800 bps.

## 4 Experimental Results

Figure 3 contains analyzed data obtained at Iceland from transmitters at Iqaluit, St. Johns, Jan Mayen, and Pena Grande. These plots address the issues of space and frequency diversity.

Figure 3a gives the percentage of successful threshold crossings, indicative of communication success, as a function of frequency band designation for each path involved and for the period 12-13-94 to 02-14-95. Several things are apparent. First we observe that the lowest and highest frequency bands have lower availabilities than the midband frequencies. We also note that the overall average availability of a given channel is of the order of 20% over the two month period. Of the 44 path and frequency combinations, only five of them corresponded to communication availabilities in excess of 60%. We see from Figure 3b that path and frequency diversity makes an immense difference in network connectivity. It exhibits the percentage availability of HF DL service for each path and for groups of 11, 8, 6, and 4 frequencies respectively. The advantage of combining paths is obvious. It is of some interest to note that if all stations are used, then 4 frequencies will suffice in this particular example. Obviously it is essential that we have a good selection of frequencies, and the more we have the better. However they must be the correct frequencies. In any case there should be no dispute that station (or path) diversity is an important mitigation tool.

It was of some interest to determine the extent to which magnetic activity has affected the HF DL performance. To do this we examined the variation of the planetary magnetic activity index  $A_p$ , a daily index, with percentage availability parametrized in terms of number of frequencies utilized. An example of such a comparison is shown in Figure 4. In this example, we show the performance of HF DL over the Wainwright to Churchill path between 24 January and 14 February 1995.



Two things are evident from Figure 4. First, we see that the number of frequencies is relatively unimportant in this example, a fact which is not always observed. Of more relevance is apparent correlation of HFDL performance and Ap. This may not be a general result, but we feel at this stage in our analysis that it will be important for transauroral paths. If this results turns out to be general, then we will have derived an additional flag for use in short-term forecasting.

We have also examined the communication unavailability for five 4-circuit networks under magnetic storm conditions and for two distinct frequency management scenarios. The first frequency management strategy involves IONCAP prediction of the best three frequencies to be allocated for each path. We call this the “squitter” approach. The second strategy involves real-time selection of the single best frequency for each path using the Chirpsounder method.

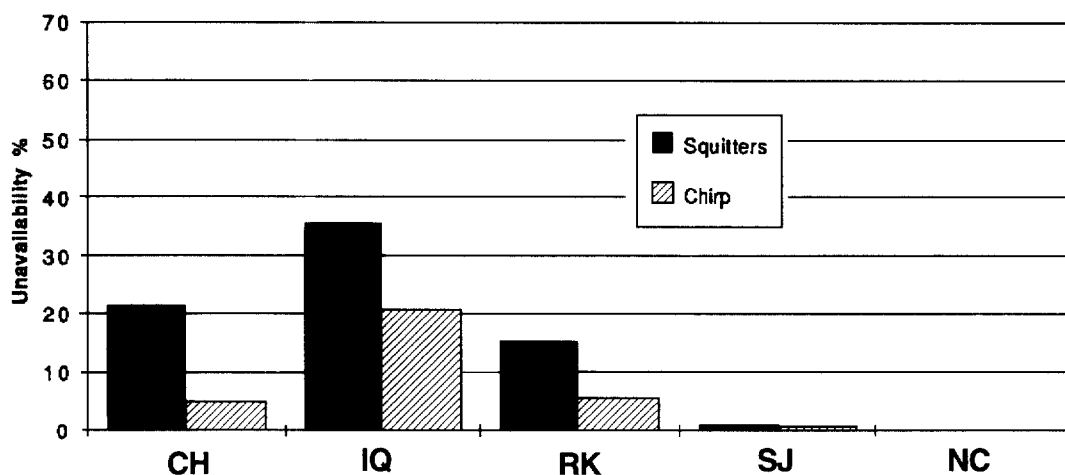


Figure 5: Communication unavailability during magnetically disturbed period in April 1995. Chirpsounder and 3-squitter methods are compared. Receiver nodes are located at Churchill (CH), Iqaluit (IQ), Reykjavik (RK), St. Johns (SJ), and North Carolina (NC). There were 4 circuits/net.

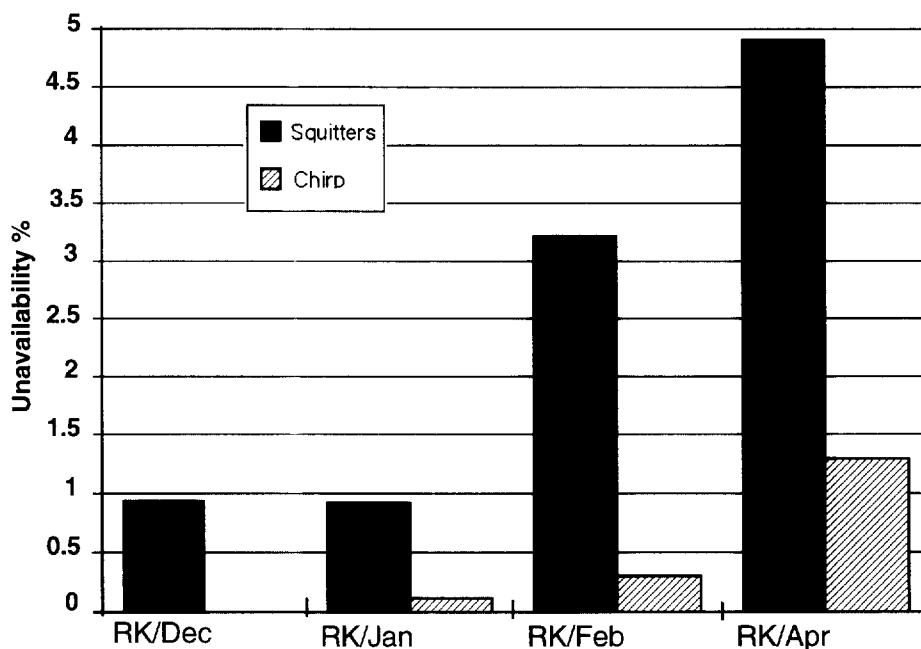


Figure 6: Communication unavailability for receiver node at Reykjavik for four months: December 1994, and January, February, and April 1995. Four circuits are considered. The transmitter nodes are Iqaluit, Jan Mayen, Madrid, and St. Johns.

In both instances, the selections are made from within the eleven aeronautical-mobile bands. Figure 5 shows the strong impact of magnetic activity on the unavailability. It is clear that sounder-based frequency management is superior to predictions. During benign conditions, the unavailabilities are vanishingly small. For months for which the magnetic activity is small, the sounder-based unavailability is less than 0.3%. Even during the fairly stormy month of April, the average unavailability is about 1.3%.

Figure 6 shows how unavailability varies over four months for a receiver in Reykjavik, Iceland. For this site, which represents conditions ranging from high mid-latitude to auroral, we note that the unavailability increases from December 1994 to April of 1995. This is principally the result of magnetic activity trends over that period, but other factors may be involved. We see that the unavailability is zero for the Chirpsounder method of frequency management during December and is about 1% for the worst-case month. The alternative method, using three fixed-frequency “squitters” (or sounds) as specified from IONCAP predictions, exhibits a decidedly poorer performance. The Chirpsounder method, incorporating full-band sounding of the entire HF spectrum, allows selection of the best frequency from within the eleven aeronautical-mobile bands, as well as information which may be used to anticipate future performance at designated bands. On the other hand, the “3-squitter” method exploits only three real-time sounds for use in selection of an appropriate frequency for transmission, and channel variability may often defeat such hybrid methods which are ultimately based upon IONCAP predictions.

#### 4 Discussion

It is worth noting that our Northern Experiment was initiated in December of 1994 and continues as of this writing. This is a period of waning solar activity, moderate magnetic activity, and is a period for which we should experience no Polar Cap Absorption events (PCA).

There have been a number of high latitude investigations of HF communication efficacy. An early study by Jull [3] specifically deals with arctic communication within the Aeronautical Mobile Allocation bands. From a frequency management context Jull found, not unexpectedly, that the best scheme involved dynamic frequency allocation. The least accurate method involved static predictions. This is the same observation we have made in connection with our 1993 study, and depicted in Figure 1.

In our studies, we have found that dynamic frequency management provides the best opportunity to achieve connectivity for a network. Moreover, the Chirpsounder method of HF channel assessment allows more consistent performance than hybrid methods which use predictions to determine a limited number of sounding frequencies (i.e., squitters) to be used in real-time channel evaluation, and Chirpsounder-driven methods offer vastly better performance than methods which rely on static predictions alone. In addition, the Chirpsounder scheme enables a more complete

description of the ionospheric channel to be obtained. This has implications for the development of a comprehensive resource management concept for regional and global HF communications.

TCI/BR is developing a dynamic ionospheric map and HF propagation forecasting capability based upon data extracted from Chirpsounder instruments. We anticipate that this capability will enhance HF communication for a number of applications, military and civilian.

A related issue of major interest is the degree of synergy which exists between HF and SATCOM. Both systems may have periods of unavailability, but if the correlation of unavailabilities for the two independent systems is sufficiently small, then a hybrid system would be preferable to either one alone. TCI/BR is planning to study this synergistic relationship in the context of high latitudes and the equatorial regions where we suspect the correlation of unavailabilities will be least.

#### Acknowledgments

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#### References

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- [2] Goodman, John M. , 1992, *HF Communications: Science & Technology*, Van Nostrand Reinhold, New York.
- [3] Jull, G.W., 1964, “HF Propagation in the Arctic”, in *Arctic Communications*, AGARDograph 78, Pergamon Press, Pergamon Press, Oxford.

## CERTIFICATE OF SERVICE

I hereby certify that a true and correct copy of the foregoing Comments of BR Communications of BR Communications was hand delivered, this 22th day of September, 1995, to each of the following:

Chairman Reed Hundt  
Federal Communications Commission  
1919 M Street, N.W., Room 814  
Washington, D.C. 20554

Hon. James Quello  
Federal Communications Commission  
1919 M Street, N.W., Room 802  
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Hon. Andrew C. Barrett  
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Hon. Susan Paula Ness  
Federal Communications Commission  
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A handwritten signature in black ink that reads "Dawn Hottinger". The signature is fluid and cursive, with a large initial "D".

/s/ Dawn Hottinger

Dawn Hottinger